(12) UK Patent Application (19) GB (11) 2 134 689 A

(21) Application No 8401577
(22) Date of filing 20 Jan 1984
(30) Priority data
(31) 8302125
(32) 26 Jan 1983
(33) United Kingdom (GB)
(43) Application published 15 Aug 1984
(51) INT CL³ G10K 10/00 A61B 5/12
(52) Domestic classification G5J 2A7 ECA ECB U1S 1032 1066 G5J
(56) Documents cited
GB A 2065020
GB A 2030763
GB 1486827
GB 0388594
(58) Field of search
G5J
H4J

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(54) Tinnitus masking

(57) Tinnitus can often be alleviated by generating sounds in a personal hearing aid (or tinnitus masker). Problems arise in characterising sounds which will be of use and in generating these sounds. An arrangement for helping to overcome these problems includes a sound generator 10 containing tone and noise generators 14—17 controlled by a microprocessor system 11 and a terminal 12 to generate a variety of types and intensities of sounds in earphones 23. The arrangement is used to characterise sounds which help a sufferer and data used to generate these sounds are recorded at 26. A similar sound generator may then form part of a personal masker controlled by a microprocessor using the data characterising the sufferer's tinnitus which is held in a read-only memory. Other forms of masker are also described. The sound generator may be synchronised with the heartbeat, using a pulse rate monitor 29.

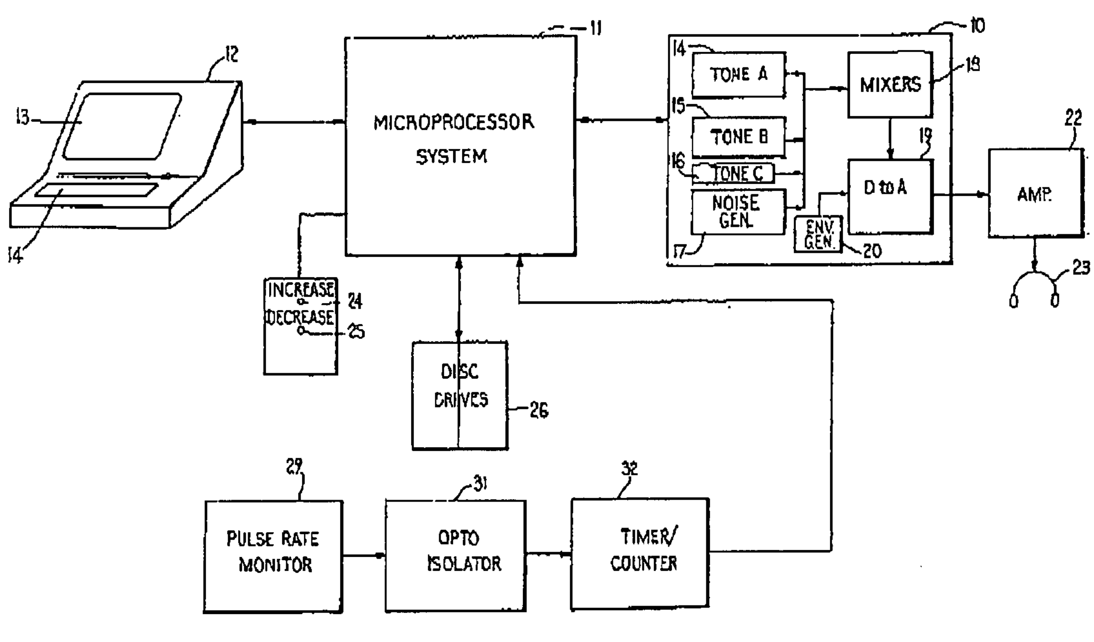

FIG.1

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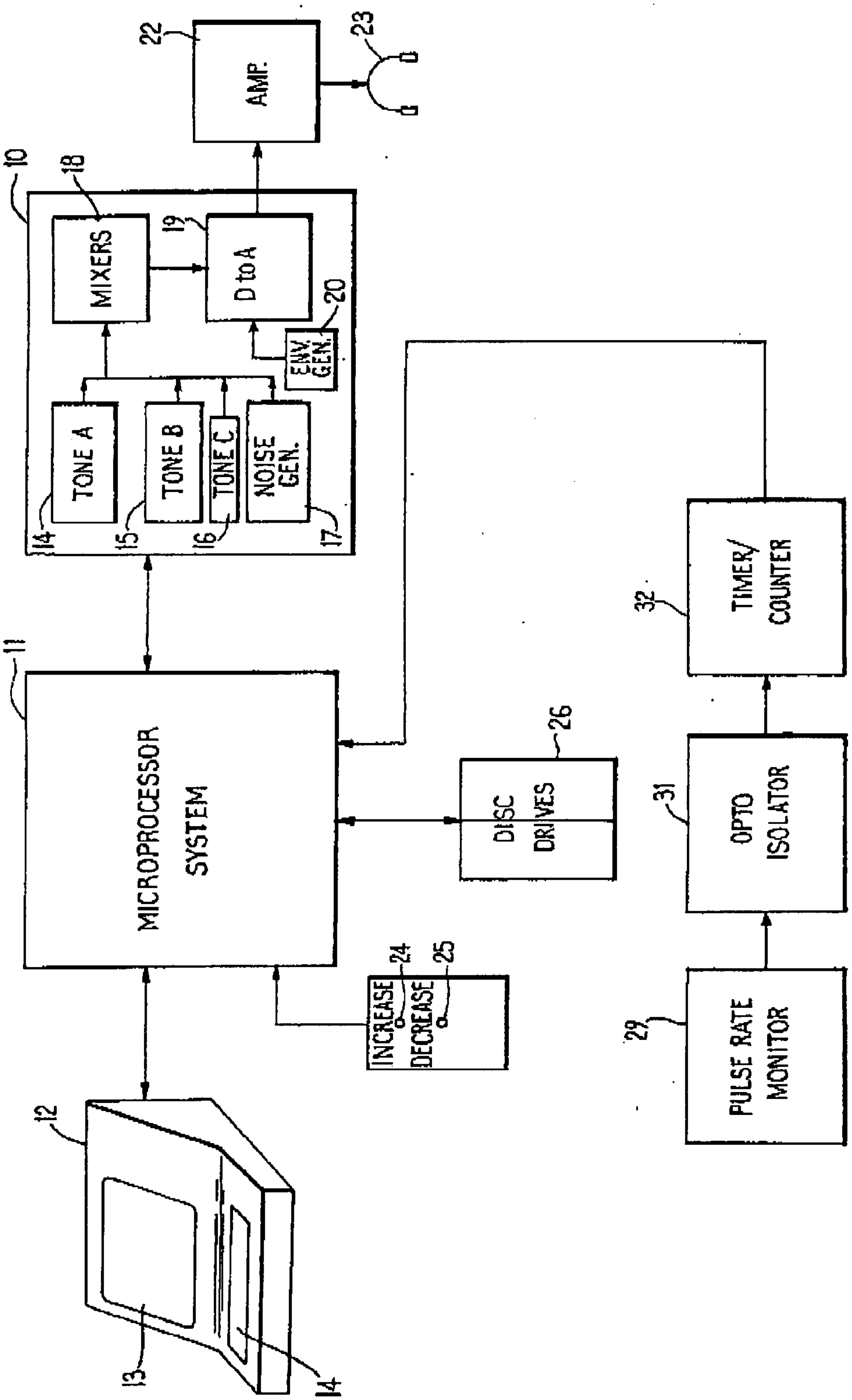

FIG.1

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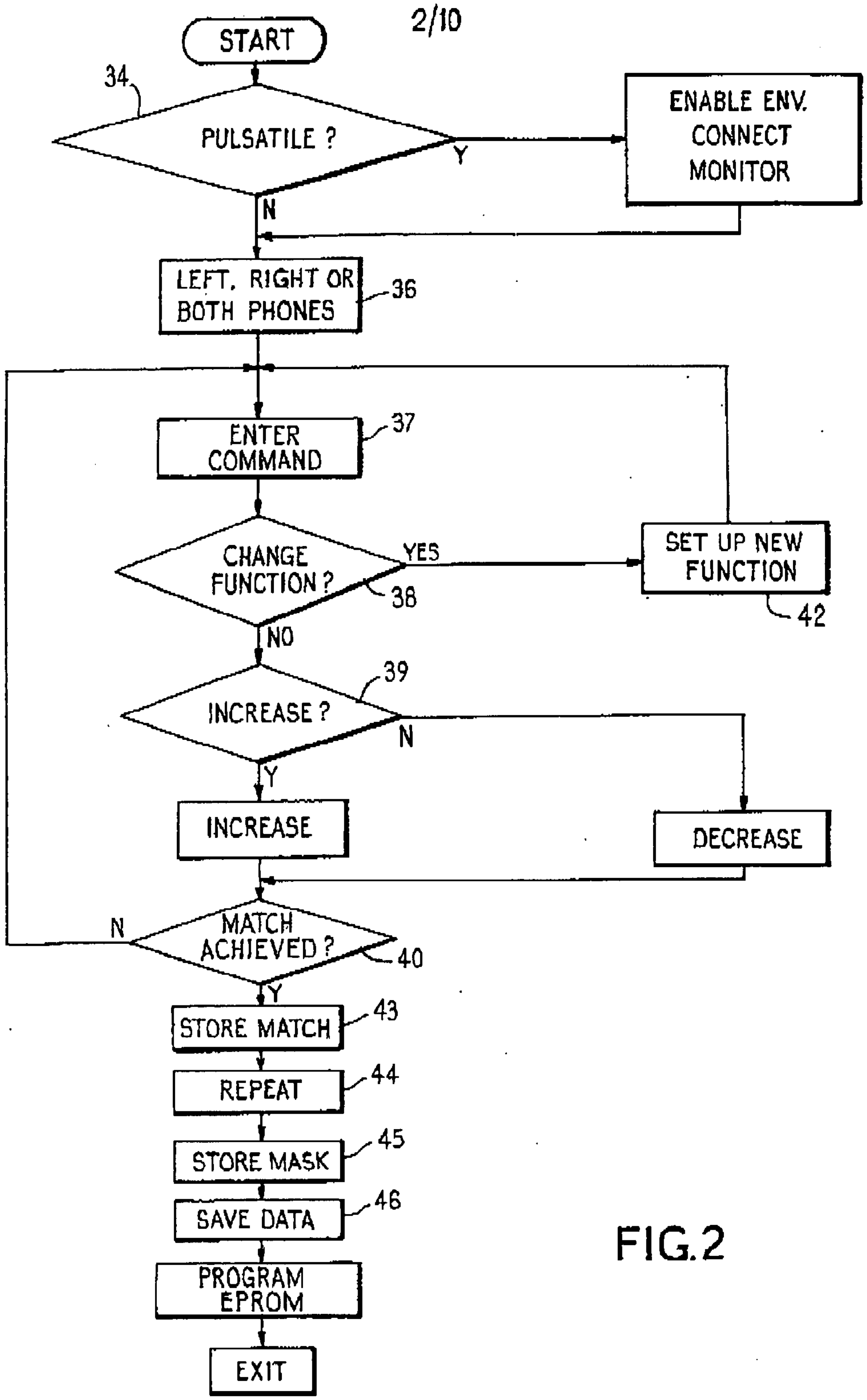

FIG.2

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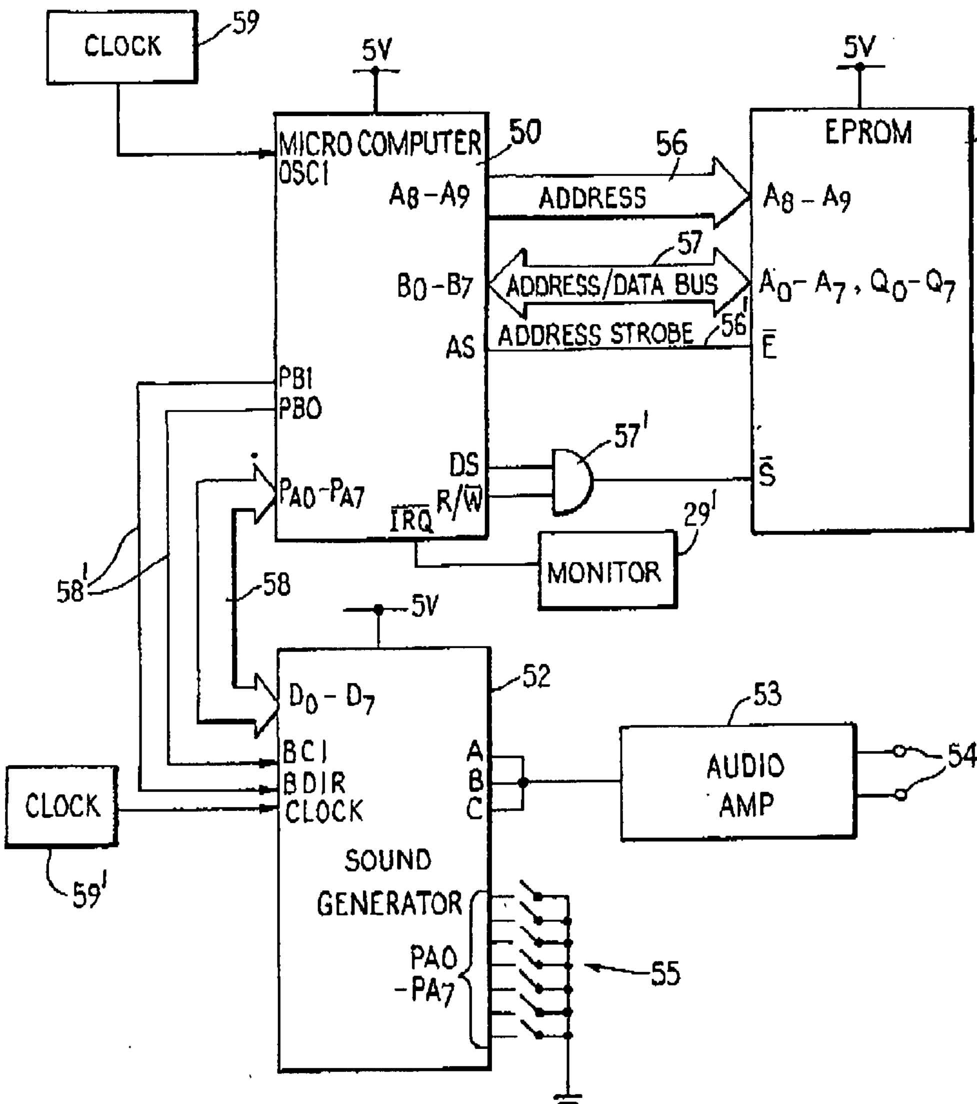

FIG.3

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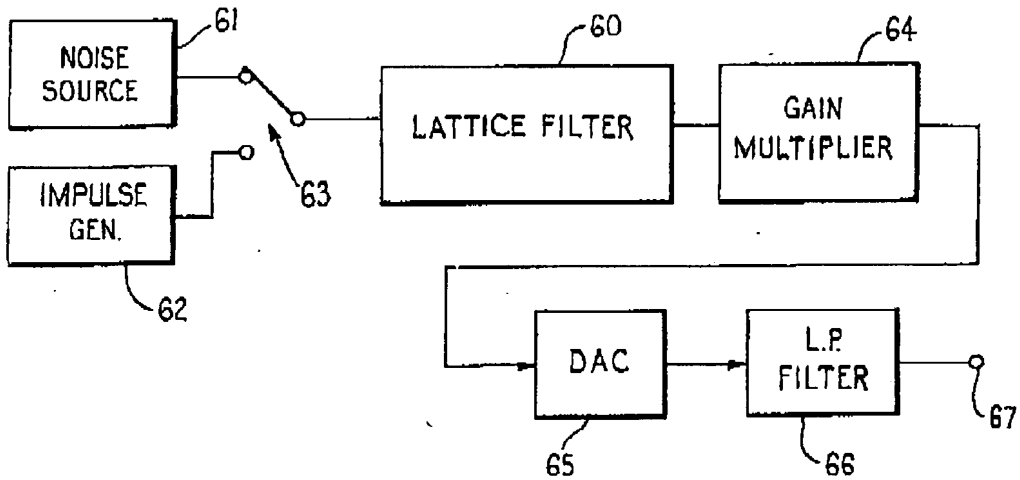

FIG.4

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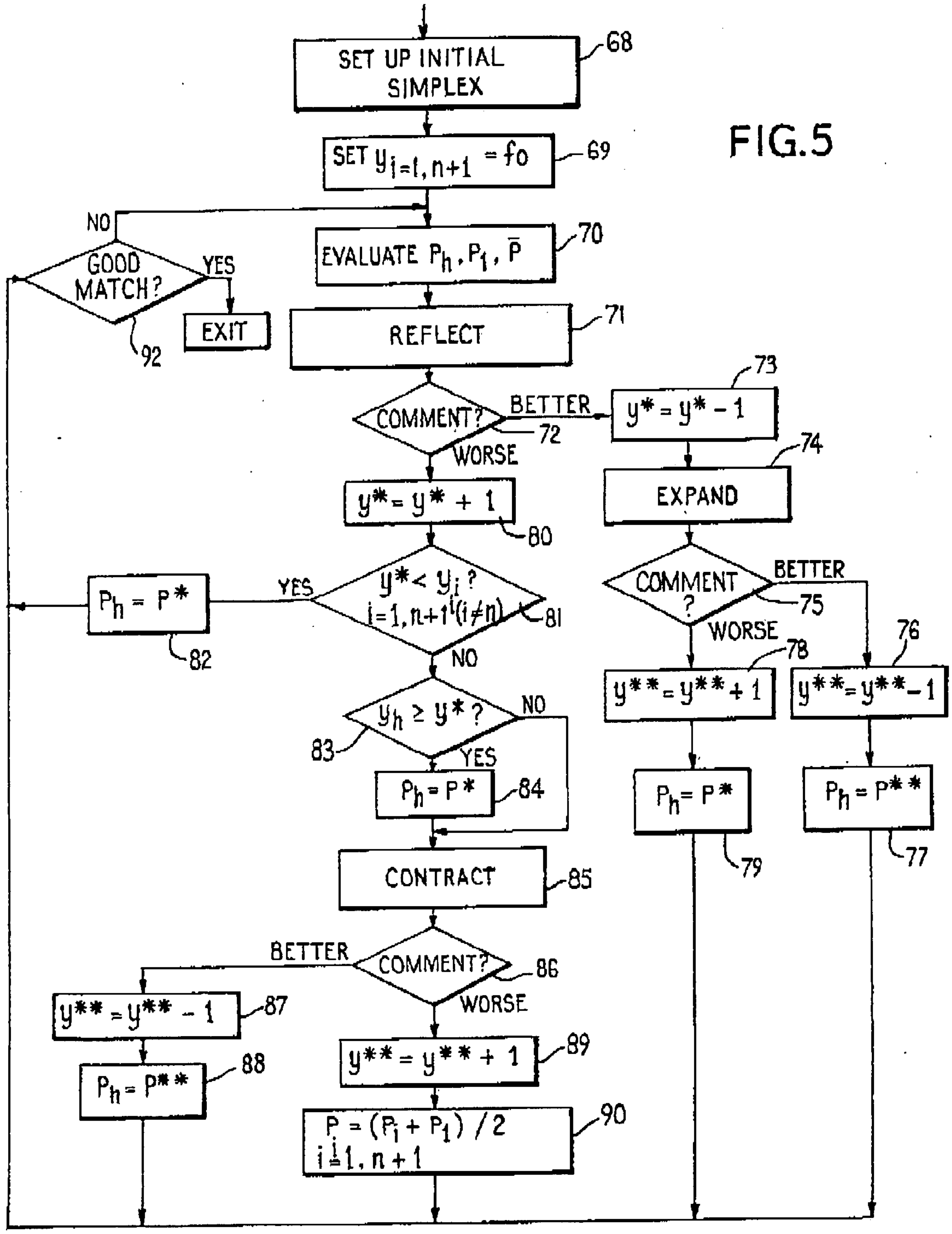

FIG.5

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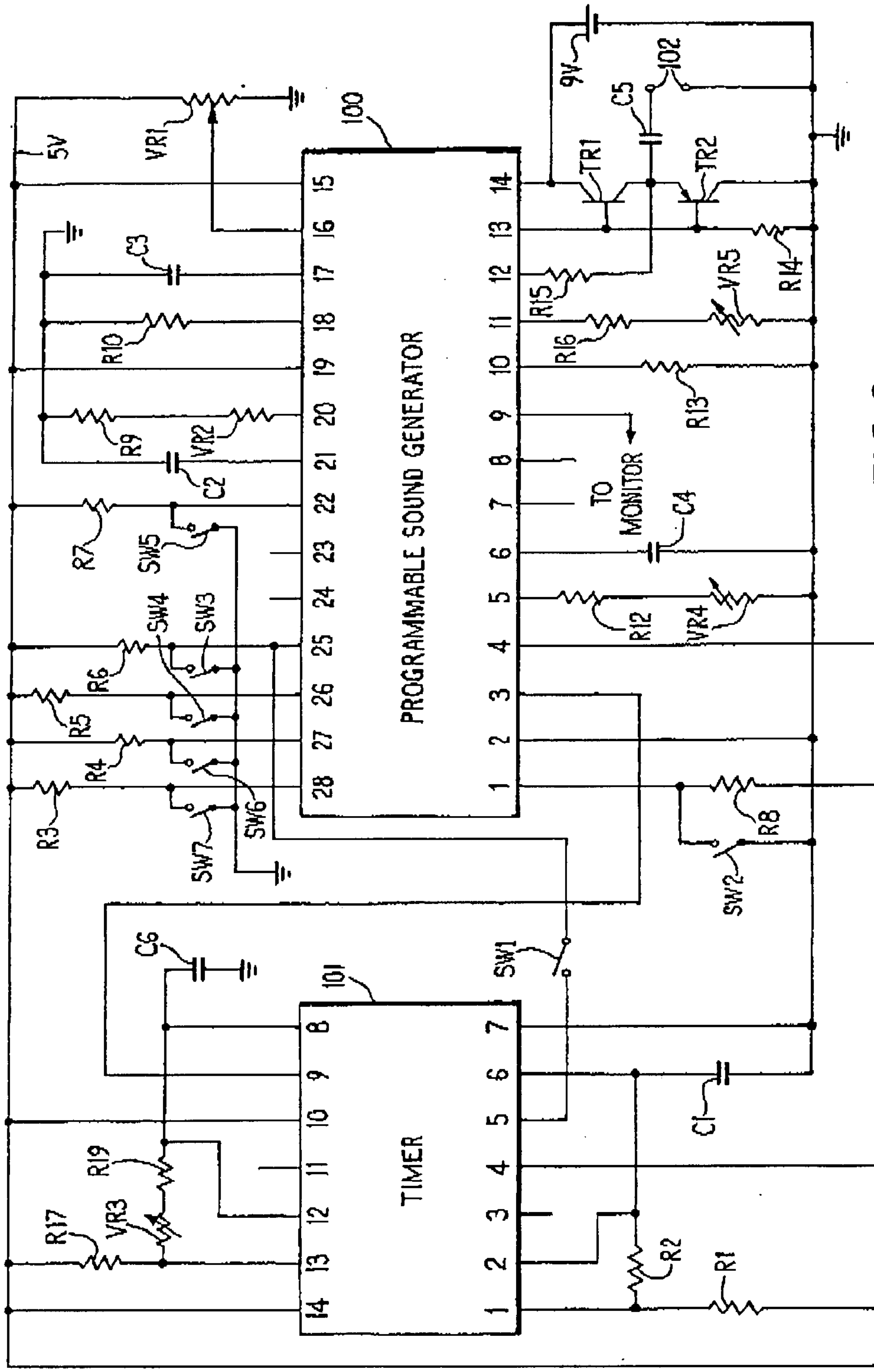

FIG.6

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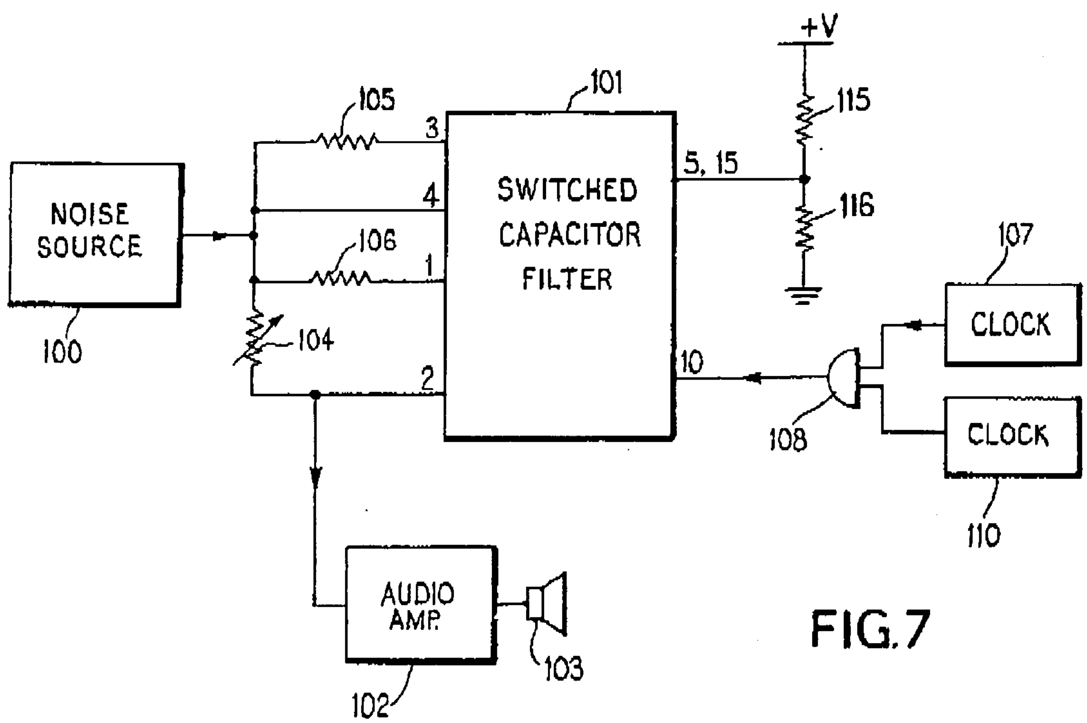

FIG.7

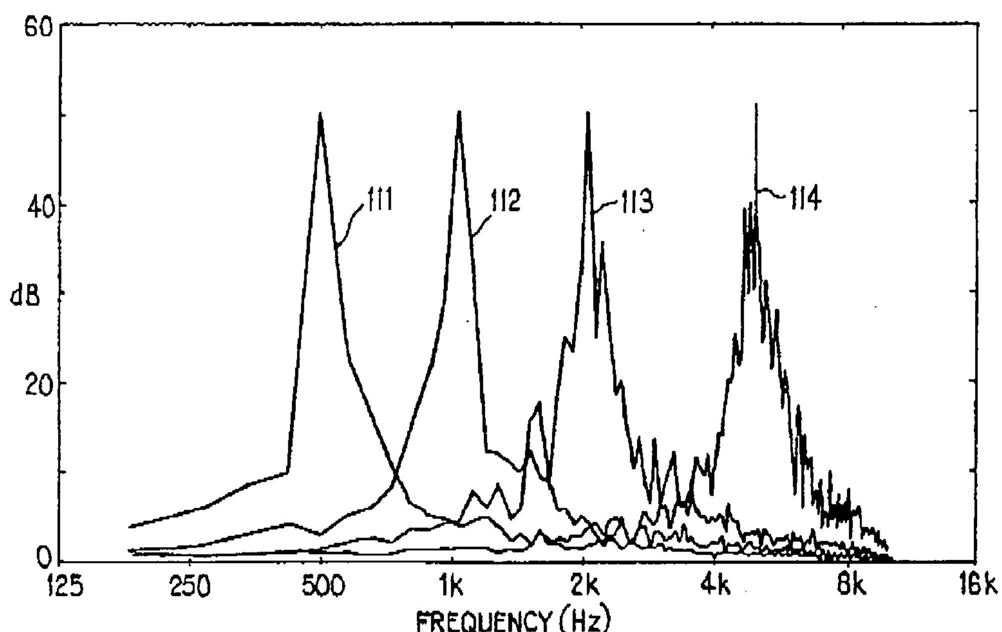

FIG.8

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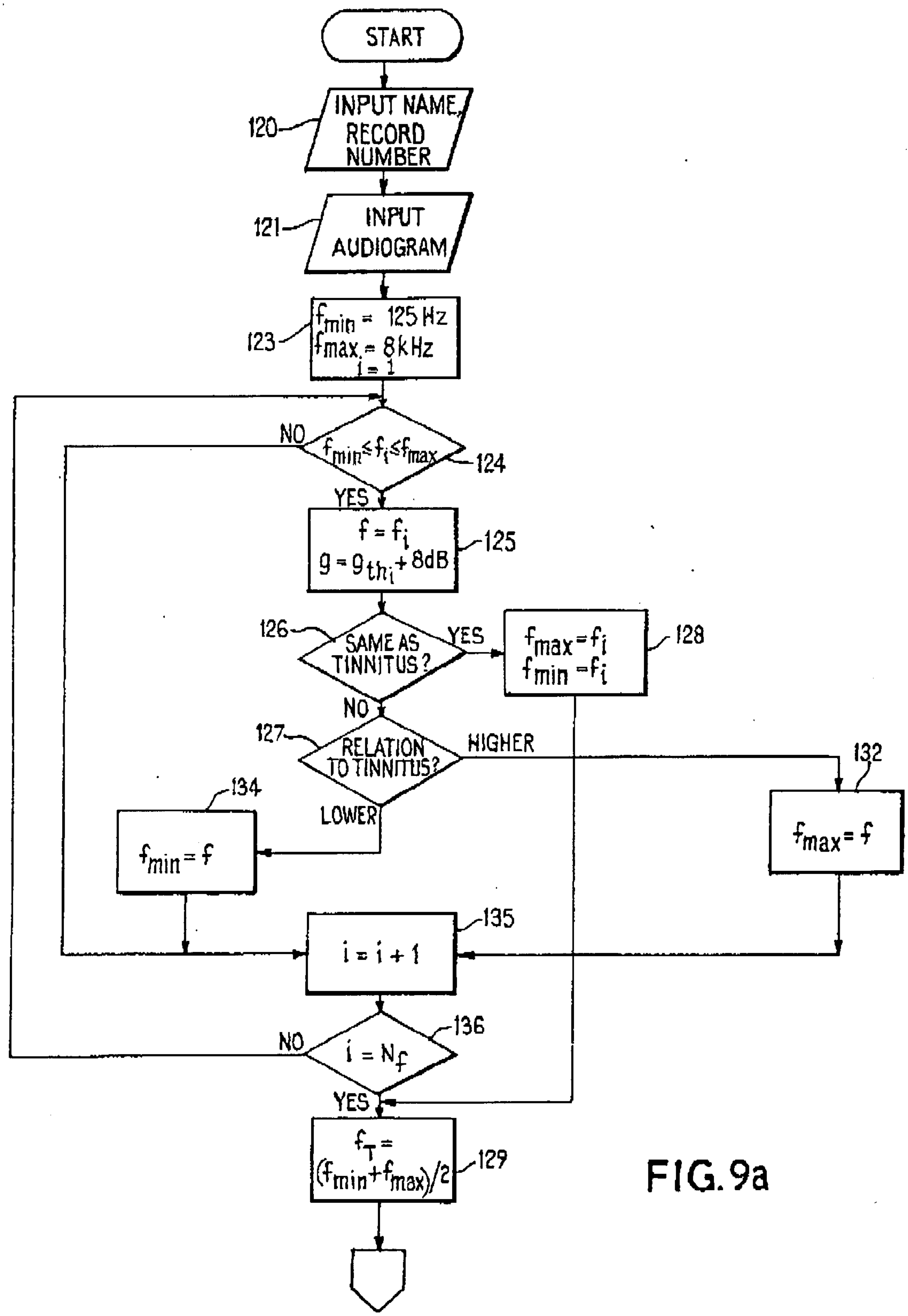

FIG. 9a

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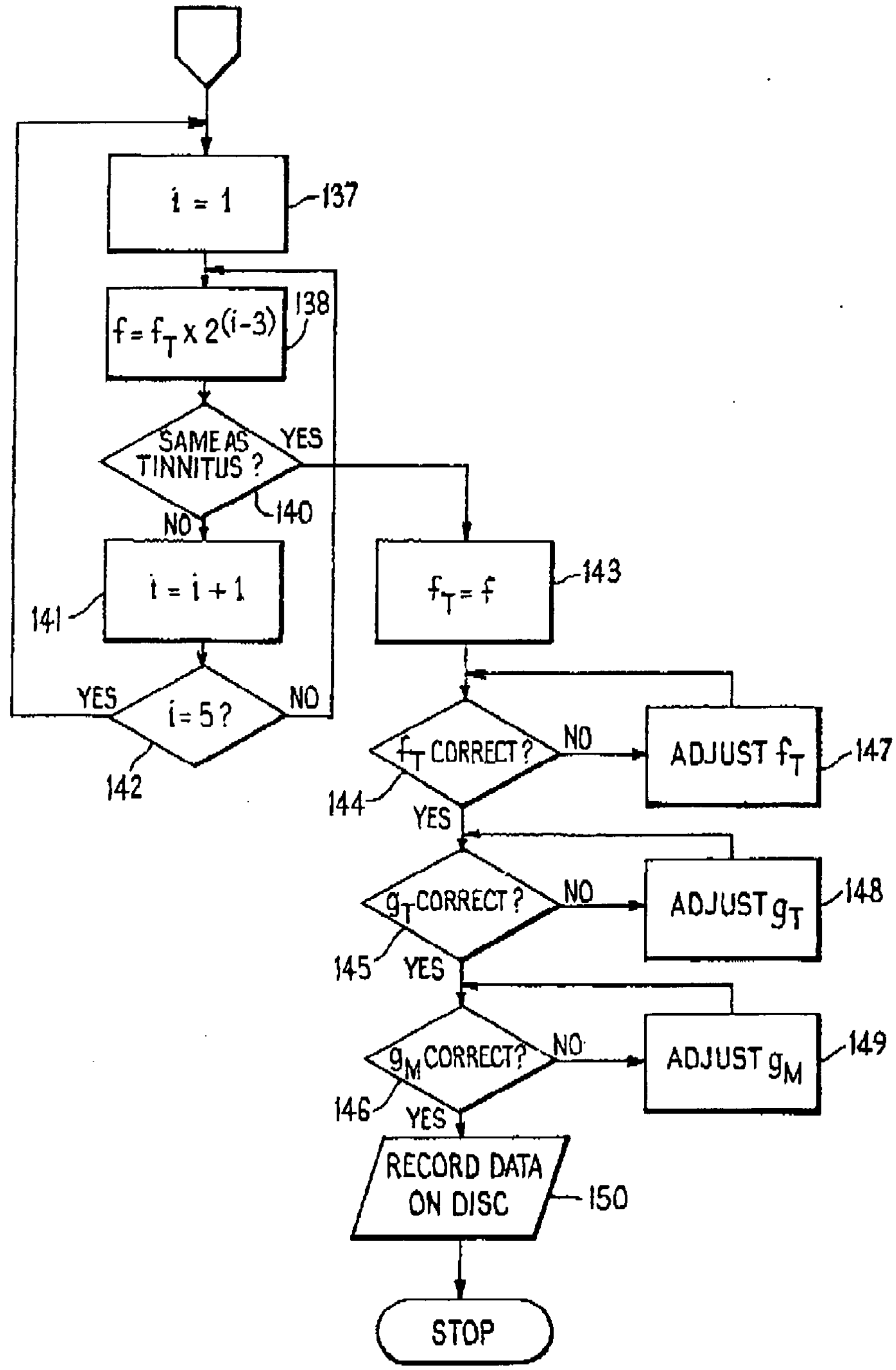

FIG.9b

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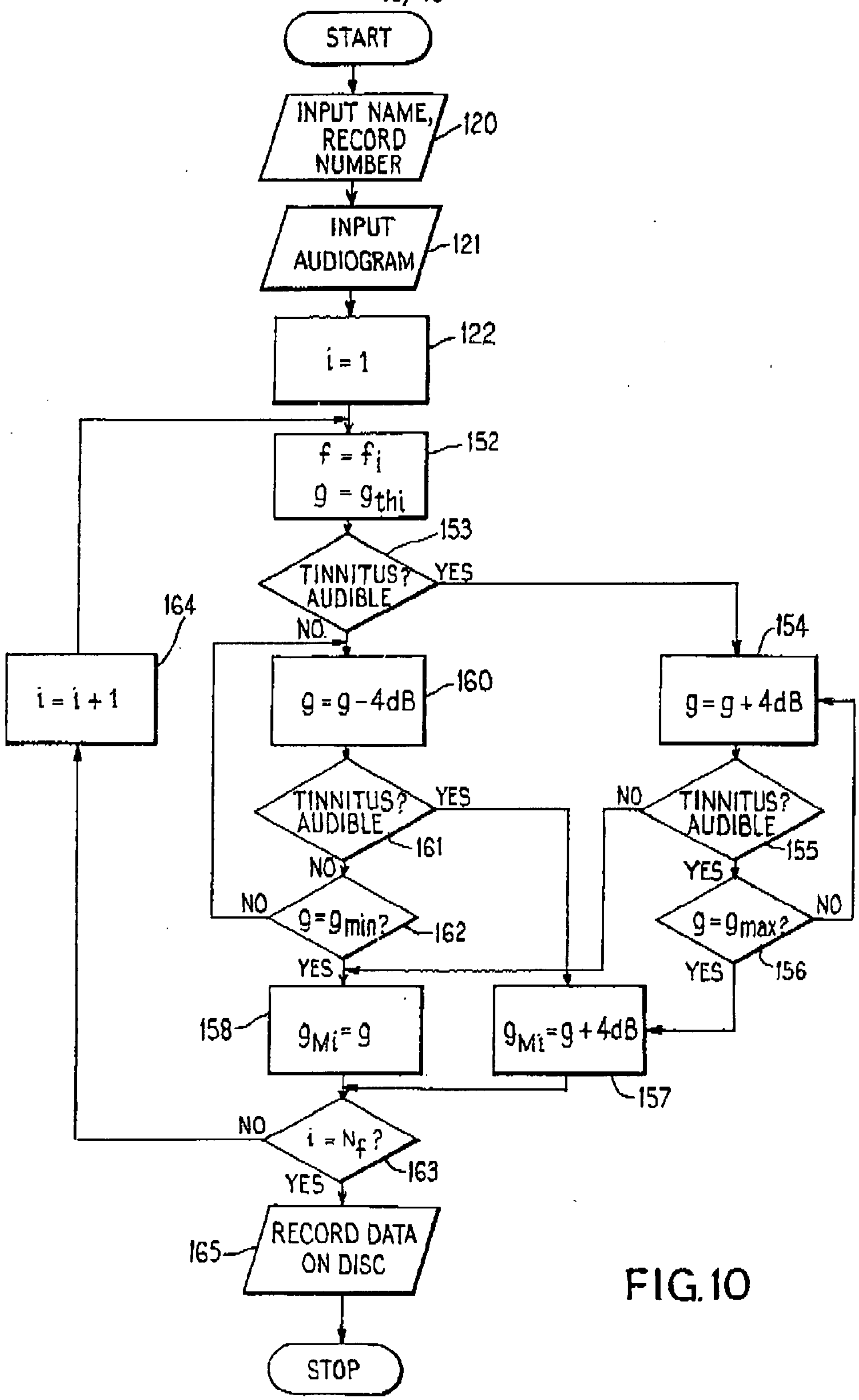

FIG.10

SPECIFICATION
Tinnitus masking

The present invention relates to apparatus for characterising sounds which alleviate tinnitus, or noise in the ears, and to apparatus for masking tinnitus.

Tinnitus is a very common complaint particularly in older people suffering from presbyacusis, other common causes being diseases of the inner ear or acoustic trauma. The noises which may be intermittent or continuous consist of a whole variety of sounds, varying from a band of noise or pure tones to sounds of bloodflow.

Tinnitus can sometimes be alleviated to some extent by injecting noise into a sufferer's ears and tinnitus maskers are available which comprise a broad band noise source and an adjustable filter. However a multitude of sounds are heard by tinnitus sufferers, many of which cannot be masked by such a noise source. Many sufferers find such a source to be unacceptable to listen to for any length of time and in fact the sound produced is sometimes rather like another tinnitus noise in addition to the existing tinnitus. Further, a continuous masking noise has been found of little use to the person who suffers from pulsatile tinnitus.

According to a first aspect of the present invention there is provided apparatus for use in connection with tinnitus comprising

at least one electrical signal-to-sound transducer suitable for positioning in, or adjacent to the ear of a tinnitus sufferer,

at least one tone-generating means coupled to the transducer for generating an alternating electrical signal which causes the transducer to generate an audible tone, and

means for adjusting the frequency and/or amplitude of the said signal.

Preferably such a masking apparatus (a masker) according to the first aspect of the invention also comprises an electrical noise source and means for adjusting at least one of the following:—

noise bandwith, the centre frequency of the noise band and noise amplitude.

In this specification and claims the term "centre frequency of a noise band" means the frequency at which peak noise intensity occurs within a band and usually approximates to the mid frequency of the band.

The advantage of such a masker is that it can be set up to generate tones and, if required, noise which can be accurately adjusted to alleviate tinnitus without generating much unnecessary and unwanted noise. Usually the tone or tones are adjusted to be the same as, or close to, the tones heard by the sufferer.

In order to mask pulsatile tinnitus the masker includes control means for controlling the tone generating means and/or the noise source so that pulses of tone and/or noise are generated by the transducer.

Although the present inventors have discovered that it may not be necessary to synchronise the pulses produced by the masker with the sufferer's heartbeat, the masker may include pulse-monitor means, adapted to be worn by the sufferer, for generating a synchronising signal once each heartbeat, the pulse monitor being coupled to the control means to synchronise the masker pulses with the heartbeat.

The apparatus according to the first aspect of the invention may also be used for characterising a sound which alleviates tinnitus so that, for example, simplified or more portable maskers can be set up. However the apparatus must then include means for indicating and/or recording at least some of the following:—

the frequency of each tone and its amplitude, and the bandwidth, centre frequency and amplitude of the noise.

The means for generating a tone and the noise source may conveniently be included in an integrated circuit under the control of a microprocessor. When such an arrangement is used, in characterising apparatus, the means for recording parameters of sounds generated may comprise a programmable read only memory (PROM). If the characterising apparatus and the masker use the same or compatible sound generating integrated circuits a PROM programmed by the characterising apparatus may be connected in to a general purpose masking apparatus.

Hence, according to a second aspect of the present invention, there is provided easily personally portable apparatus for use by a particular tinnitus sufferer comprising

at least one electrical signal-to-sound transducer suitable for positioning adjacent the ear of the said sufferer,

at least one tone generating means coupled to the transducer for generating an alternating electrical signal which causes the said transducer to generate an audible tone having a frequency and/or amplitude such that the tinnitus of the said sufferer is alleviated.

Preferably apparatus according to the second aspect of the invention also includes noise generation means and means for generating a signal envelope which may be in synchronism with the sufferer's heartbeat.

The apparatus for characterising tinnitus according to the first aspect of the invention may comprise a simple control for use by a sufferer for indicating by means of possible first and second actions only whether a sound generated by the apparatus is more or less like the sufferer's tinnitus, or is more or less effective in masking the tinnitus. The characterising apparatus then includes means for adjusting the sound generated by the transducer in accordance with the signals from the sufferer's control.

The means for adjusting the said sound may include an adjustable electrical filter and means for implementing a simplex method which evaluates poles of the filter each time the

sufferer's control is operated. The simplex is arranged to gradually converge to an optimum set of poles.

According to a third aspect of the invention there is provided apparatus for use in connection with tinnitus comprising at least one electrical signal-to-sound transducer suitable for positioning in, or adjacent to, the ear of a tinnitus sufferer, at least one electrical noise source, and means for selecting both the centre frequency of a noise band for application to the transducer and the bandwidth of the noise band.

Certain embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:—

Figure 1 is a block diagram of a characteristation system according to the invention,

Figure 2 is a flow chart showing a matching procedure used in setting up a masker,

Figure 3 is a block diagram of a masker according to the invention,

Figure 4 is a block diagram of a speech synthesiser used in characterising tinnitus with a simplex algorithm,

Figure 5 is a flow chart of the simplex algorithm,

Figures 6 and 7 are block diagrams of further maskers according to the invention,

Figure 8 shows output noise spectra which may be obtained with the circuit of Figure 7,

Figures 9a and 9b form a flow chart for matching a tone to a tinnitus, and

Figure 10 is a flow chart for measuring tinnitus masking by a tone at various frequencies.

Tinnitus characterisation and the specification of sounds for a masker are carried out using the apparatus of Figure 1 having a type AY-3-8912 programmable sound generator (P.S.G.) integrated circuit 10 interfaced to a microprocessor development system 11 based on a 6809 central processing unit. The development system available from Southwest Technical Products, Tresham Road, Orton Southgate, Peterborough, England may be used. The development system 11 is also interfaced to a terminal 12 comprising a visual display unit 13 and a keyboard 14.

The P.S.G. 10 comprises three tone generators 14, 15 and 16 which can be programmed in frequency and amplitude and a pseudo random nose source 17 generating a band of noise having an adjustable centre frequency. Programming of any particular one of these parameters is accomplished by entering a number into one of eleven registers in the P.S.G. For example a number in the range 0 to 15 is loaded into the amplitude register of any of the tone generators or the noise source in order to set the output intensity, and a number representing the period of a tone is loaded into the tone register. The tone generators and noise source feed three mixers 18 coupled to a digital-to-analogue converter 19 with three output channels. The converter 19 also receives signals from an envelope generator 20 under the control of three further P.S.G. registers which allow the shape and period of the envelope of each of the three channels to be controlled. The three channels are commoned and coupled to an audio amplifier 22 which feeds headphones 23 for a tinnitus sufferer.

The terminal 12 is used to set up any required tones and noise by controlling the contents of the P.S.G. registers. Two external push buttons 24 and 25 in parallel with two keys on the keyboard 14 are provided for the sufferer's use as is described below.

Envelope generation is not used to characterise a continuous tinnitus. Tones and noise are varied as is described below until the sufferer reports that the sounds generated in the earphones are the same as those of the tinnitus. The values of the variables entered into the registers of the P.S.G. are recorded on a floppy disc using floppy disc drives 26.

The inventors have discovered that pulsatile tinnitus can be alleviated if the sound which the sufferer apparently hears is also pulsatile and in addition it is often helpful if the pulsatile sound is synchronised with the heartbeat. To this end a pulse rate monitor 29 which provides an output pulse each time a heart-beat occurs is used. A suitable type of monitor is described by T.R.M. Brown and J. MacGregor in "An Infra-red Reflectance System for Ambulatory Characterization of Left Ventricular Function" in the Journal of Biomedical Engineering, 1982, Vol. 4, April. The monitor is battery operated for safety and for the same reason coupled by way of an opto isolator 31 to a timer/counter 32. At each heartbeat the timer counter provides an interrupt signal for the microprocessor and passes a digital signal representative of the interval between the current and previous heartbeats. This interval is passed to the P.S.G. and used as the duration of the next envelope pulse.

Tinnitus characterisation is carried out using a matching algorithm; a flow chart of which is given in Figure 2. A program corresponding to parts of the algorithm is held by the system 11.

From a verbal description of the tinnitus by a sufferer, the audiologist answers the question 34 and positions the electrodes if the tinnitus is pulsatile. He also enters commands enabling the envelope generator in the P.S.G. and switches on the pulse monitor.

In an operation 36 the program then prompts using the VDU for left, right or both headphones to be selected and the audiologist enters an appropriate command.

Using the verbal description again, the audiologist experiments with various sounds entering commands generating one of these sounds in an operation 37. The program then prompts for the adjustment of one function, for example the frequency or amplitude of a tone, or the centre frequency or amplitude of a noise band. The audiologist is asked to indicate in an operation 38 whether this function is to be set up or a change to another function made; that is

whether the register in the P.S.G. controlling the function is to be selected or whether another such register is to be selected. If the current function is to be adjusted a question 39 is prompted by the VDU and the sufferer responds by pressing either button 24 (increase) or button 25 (decrease), and this has the effect of increasing or decreasing the contents of the selected register. Further questions prompted by the VDU ask if a match is achieved (question 40) and if not whether the function currently being adjusted is to be replaced (question 38) and whether the current function should be increased in frequency or amplitude (question 39). An operation 42 selects a new function in sequence when a change is required.

When the sufferer reports that the sound generated is as near as possible to the tinnitus, the answer to question 40 causes the system 11 to store the values obtained in an operation 43.

Once a match has been achieved, the audiologist and sufferer can go about finding the optimum form of masking noise by repeating the operations 37 to 42 in an operation 44 but this time with the idea of alleviating the tinnitus rather than characterising it. The information stored in the operation 43 is used as a basis for obtaining the masking noise. In many cases the results will be much the same since the correct form of masking will be a sound which matches the tinnitus. In a few cases, the sufferer might judge the match to be unacceptable masking noise, probably due to the fact that some sufferers find difficulty in discriminating external sounds on top of the tinnitus. Hence such sufferers might specify by means of the operation 44 a sound close to the tinnitus which they perceive as a match, but is in fact not close enough. This is then perceived as another noise which is just as bad as the tinnitus. In this instance, a selected noise band or conventional broad band masking usually suffices.

After the masking noise has been specified it is stored and then transferred to disc in operations 45 and 46, so that it can be used for record purposes or to set up a masker of, for example, the type described below with reference to Figure 6.

An alternative algorithm to that of Figure 2 is now described. In Figure 9a the sufferer's name and record number are entered together with the sufferer's audiogram (frequency response of the ear at the frequencies f_i mentioned below) in operations 120 and 121, if they have not been entered before. The next part of the algorithm is concerned with matching the frequency of a tone to the sufferer's tinnitus (whether tonal or narrow band noise) by a bracketing technique in which the sufferer is presented with a high and low pitched tone alternately. The tone presented to the sufferer is at a frequency selected from the array:—

f_i (Hz)=8k, 125, 4k, 250, 2k, 500, 1k.

In an operation 123 two variables f_{min} and f_{max} representing minimum and maximum frequency are set to the extremes of the above array and a variable i forming the array subscript is set to 1. Next a test 124 is carried out to see whether the currently selected value of f_i is within the range f_{min} to f_{max}, inclusive. If so then the frequency f supplied to the headphones 23 is set to f_i and the level g at the headphones is set to the sufferer's threshold (g_{thi}), at the frequency f_i, plus 8 dB (operation 125). Tests 126 and 127 involving response from the sufferer who uses the buttons 24 and 25, are carried out to determine whether f_i is the same as the frequency of the tinnitus, or whether it is higher or lower in frequency. If the test 126 indicates that f_i is the same as the tinnitus then f_{max} and f_{min} are set to f_i in an operation 128 and then the frequency of the tinnitus is characterised as being the mean of f_{min} and f_{max} in an operation 129. If the test 127 is carried out and f is higher than the tinnitus then f_{max} is set to f in an operation 132 so narrowing the bracketing mentioned above. If the test 127 indicates that f is lower than the tinnitus then f_{min} is set to f (operation 134). Followintg the operations 132 or 134 the variable i is incremented (operation 135) and then tested (test 136) to determine whether all frequencies in the array have been used in testing; that is i is equal to the number (N_f) of frequencies in the array. If not then a return is made to test 124 but if so then the operation 129 is carried out to average the current values of f_{min} and f_{max}. The operation 124 determines whether the new value of f_i is within the range determined so far and if not the operation 135 is carried out to increment i immediately.

The next part of the procedure for matching a tone to a tinnitus is shown in Figure 9b and starts with a check to ensure that the tinnitus frequency f_T is in the correct octave, so eliminating the possibility of the sufferer having matched the tinnitus to the wrong octave. In operation 137 i is set to 1 and then the test frequency f is set to $f_T \times 2^{(i-3)}$ (operation 138). In a test 140 the sufferer signifies by means of an entry to the keyboard 14 made by an operator whether the frequency f is the same as his tinnitus and if not the value of i is incremented (operation 141) and then tested (test 142) to determine whether i=5. If not then test 138 is repeated but if i is equal to 5 then operation 137 is carried out again setting i to 1 so that the procedure for checking the frequency f_T is carried out until a positive response is obtained from the test 140, f_T then being set to f in an operation 143.

Finally a method of adjustment wherein the parameter measured is increased or decreased in steps in accordance with the sufferer's response, is used to fine tune f_T to balance the loudness of the tone to the tinnitus loudness (g_T) (that is when the sufferer can hear both the tone and the tinnitus equally loudly) and to measure the level of sound which just maskes the tinnitus (g_M) (that is where the tinnitus can just not be heard because of the tone). Typically, g_M is about 10 dB above g_T. These adjustments are made by means of tests

144, 145 and 146 and adjustment operations 147, 148 and 149. The parameters f_r, g_T and g_M are recorded on disc in an operation 150.

An algorithm, shown in Figure 10, is now described for measuring the level of sound (either a tone or narrow band noise) which just masks a tinnitus at the different frequencies of the array f_i defined above. This algorithm is used for measuring the tinnitus masking threshold and can be performed for example immediately after that of Figures 9a and 9b. Sound is presented to the sufferer in the same ear as his tinnitus and he then responds with one of the two push buttons 24 or 25. Operations 120 and 121 are the same as the corresponding operations in Figure 9a and they are followed by an operation 122' in which the variable i is set to 1. A frequency of testing f is set to f_i and the level g is set to g_{thi}, available from the sufferer's audiogram, in an operation 152. A test 153 is then carried out to ask the sufferer whether the tinnitus is audible and he uses the button 25 to indicate that the tinnitus is audible. If so then the loudness of the tone or noise f is increased by 4 dB in an operation 154 when a further test 155 is carried out to determine whether the tinnitus is still audible. If so then a test 156 is carried out to determine whether g has reached a level g_{max} which is the upper limit of the generator 10 intensity. If this limit has not been reached then the operation 154 is carried out again but if it has been reached then a final level to be recorded for this frequency (g_{Mi}) is set 4 dB higher than the current value of g in an operation 157 (since the test 156 indicates that the generator 10 is not able to provide the required level). If the output of the test 155 indicates that the tinnitus is inaudible then g_{Mi} is set to g (operation 158). If the test 153 indicates that the tinnitus is not audible then g is reduced by 4 dB in an operation 160 and then further tests 161 and 162 are carried out to determine whether the tinnitus is still inaudible and to determine whether g has reached the lower limit g_{min} which the generator 10 can produce. Appropriate values for g_{Mi} are then recorded in operations 157 or 158. At this point a test 163 is carried out to determine whether the procedure has been carried out at all the values i of the frequencies f_r. If not then i is incremented (operation 164) but if so then the various values of g_{Mi} obtained are recorded in an operation 165.

Once the optimum form of masking has been determined it is then implemented in a portable masker. To set up the masker an Erasable, Programmable, Read only, Memory (EPROM) is programmed with data derived using the algorithm, and the EPROM is fitted into the masker.

Since data for the P.S.G. type AY-3-8912 and the 6809 processor are available from the manufacturers no further design details of the arrangement of Figure 1 are given here. Details of the program for the development system 11 will be apparent from the flow chart of Figure 2 and the above mentioned manufacturer's data.

A suitable masker (see Figure 3) comprises a low power microcomputer 50 (type MC 146805E2), an EPROM 51 (type IM 6658) and the same P.S.G. 52 (type AY-3-8912) as is used in the characterisation system. Thus the masker and characterisation system are complementary and the data derived by the system can be held by the EPROM for direct use by the P.S.G.

The data in the EPROM is addressed using an address bus 56, and address strobe 56' and an address/data bus 57. Data is strobed using an AND gate 57' and passes by way of the bus 57 to the microcomputer 50. A bus 58 transfers the data between port A of the microcomputer and the data input of the sound generator 52, under the control of signals on connections 58'. A 1 MHz clock 59 and 2 MHz clock 59' synchronised thereto are connected to the microcomputer 50 and the generator 52, respectively.

The EPROM also contains a program which allows the microcomputer 50 to control the P.S.G. by loading numbers selected by the tinnitus matching algorithm into the various registers. In order to provide a variety of masking sounds the EPROM may contain a selection of different register contents for the P.S.G. so that where the tinnitus is variable in nature the required sound can be selected by means of external switches 55 coupled to terminals PA0 to PA7 of the P.S.G. 52. As in Figure 1, synchronisation of the masking sound envelope with the heartbeat can be achieved by means of a monitor 29' connected to the $\overline{IRQ}$ terminal of the microcomputer 50. No timer/counter is shown in Figure 3 since the microcomputer 50 has internal circuits for this purpose.

The three analogue outputs of the P.S.G. 52 are again commoned together and connected to the input of an audio amplifier 53 with output terminals 54 for connection to headphones.

A preferred method of tinnitus characterisation prior to setting up a masker employs the development system 11 of Figure 1, the terminal 12, the push-buttons 24 and 25, and the disc drives 26 together with the speech synthesiser integrated circuit (type-Texas TMS 5200) and an anti-aliasing filter. A simplified block diagram of the synthesiser and the anti-aliasing filter is given in Figure 4 and includes an eight pole lattice filter 60 driven by either a pseudo random noise source 61 or a pulse generator 62 which generates impulses with a low mark space ratio. Switch means 63 allows either the noise generator or the impulse generator to be connected to the filter as required. To control the synthesiser the filter coefficients, gain and pitch period are loaded into registers in the integrated circuit of the synthesiser.

In operation data is fed continuously to the synthesiser by the development system 11 updating eight filter coefficients, the pitch period and gain at intervals of one pitch period (about 100 ms). (The terms "pole" and "coefficient" are synonymous but the contex sometimes makes

one term preferable, and sometimes the other). When the noise generator 61 is selected only a fourth order filter is required and four coefficients are set to zero, otherwise all eight poles are used for the impulse source. The output from the filter is multiplied by a gain scaling factor in a multiplier 64 and the output proceeds by way of a digital-to-analogue converter 65 and an anti-aliasing low pass filter 66 with a cut-off frequency of 4 kHz to output terminal 67 for the connection of headphones. The circuits 61 to 65 are part of the TMS 5200 integrated circuit and the filter 66 is external to this circuit.

Data for the synthesiser is obtained by first digitising a sound played on a tape recorder and then coding it using a linear prediction coding algorithm as described in the book "Linear Prediction of Speech" by Markel and Gray published by Springer-Verlag, Berlin, Heidelberg, 1976 in order to produce a set of filter coefficients for each 100 ms time sample. The choice of input source to the filter for a particular interval between samples depends on whether the interval is judged to consist of unvoiced sound when the noise source is used or voiced sound when the impulse source is used. This choice is made by the coding algorithm. A useful source of tinnitus sounds is a recording available from the Royal National Institute for the Deaf.

The development system is used to play through a library of sounds held on a floppy disc and the sufferer is usually able to select a sound which is like his tinnitus or which he finds alleviates his tinnitus. In order to achieve a better match two of the poles of the lattice filter are adjusted. This amounts to filtering the original sound with an adjustable two pole filter. The adjustment is made by a simplex algorithm which prompts the sufferer use the buttons 24 and 25. The simplex algorithm evaluates a set of poles after each trial and prompts for comment on the new sound. Based on the decision and the previous decisions the algorithm gradually converges to the required set of poles, the number of iterations usually being between about ten and thirty.

A flow chart of the simplex algorithm used (see Figure 5) is an adaptation of the original algorithm as detailed in the paper "A simplex method for function minimisation" by J. A. Nelder and R. Mead, published in the Computer Journal 7, 308, 1965. The main difference is that the simplex of the paper was designed for minimisation of a function dependent on a set of variables. In the present application the variables are two poles of a digital filter, but initially the function is not known.

In effect the function to be minimised is the subjective difference between a synthesised sound and the sufferer's tinnitus.

In the general case, if we have a function y dependent upon n variables, a simplex can be defined as a set of (n+1) points in n-d space, where P0, P1, . . . Pn are the coordinates of the vertices of the simplex. Each point has an effective function value which is stored in a n-dimensional array y[1] . . [n]. Defining h as the suffix such that

$$y_h = \max (y_i) \text{ (h for high)}$$

and 1 as the suffix such that

$$y_l = \min (y_i) \text{ (l for low)}$$

Further, $\overline{P}$ is the centroid of the points with i<> h, and $[P_iP_j]$ is the distance from P_i to P_j. At each stage in the process, the worst point P_h is replaced by a new point by one of three operations: reflection, contraction or expansion. These are defined as follows: A reflection to a point P* is defined by

$$P^* = (1+\alpha)*\overline{P} - \alpha*P_h$$

where α is the reflection coefficient (a positive constant). P* lies on the line $P_h\overline{P}$ on the opposite side of $\overline{P}$ from P_h such that $[P^*\overline{P}] = \alpha*[P_h\overline{P}]$. An expansion to a point P** is defined by

$$P^{**} = \gamma * P^* + (1-\gamma)*\overline{P}$$

where γ is the expansion coefficient (a positive constant greater than unity). P** is a point expanded away from $\overline{P}$ such that $[P^{**}\overline{P}]/[P^*\overline{P}] = \gamma$. A contraction to a point P** is defined by

$$P^{**} = \beta P_h + (1-\beta)*\overline{P}$$

where β is the contraction coefficient (a positive constant between zero and unity). P** is a point contracted towards P such that $[P^{**}P]/[P_h\overline{P}] = \beta$.

The values of α, β, γ which have been chosen empirically are 1.0, 0.5, 1.5 respectively.

The algorithm starts by setting up an initial random simplex with each point being given an initial function value (y_i) of f_0 (200 is a convenient value). Whenever the simplex makes a movement to a new point using one of its three operations it prompts for a comment and the function value at that point is incremented for a "worse" comment or decremented for a "better" comment. Hence as more entries are made, the array of function values y[l] . . [n] gradually assumes a shape corresponding to a rough error surface for the error between the current sound and the target sound.

After initialisation as described above (operations 68 and 69—see Figure 5), the points (P_l, P_h) giving the best and worst match as indicated by the sufferer and the center of gravity $\overline{P}$ of all the points are evaluated in an operation 70. The worst point P_h is then reflected (as defined above) in an operation 71 about the centre of gravity $\overline{P}$ to produce a new point P*. If P* is a better point, as indicated by the sufferer in a test 72 then a function value y* corresponding to P*, initially set at 200, is decremented by one (operation 73) and the simplex expands (as defined above) further away from P* (operation

74) to produce a new point P^{**}. If a test 75 indicates that the expanded point is better then a function value y^{**} corresponding to P^{**}, initially set at 200, is given decremented by one (operation 76) and the worst point P_h is replaced by the point P^{**} (operation 77). If P^{**} is worse than P^*, y^{**} is incremented (operation 78) and P_h is replaced by P^* (operation 79).

If the reflection 71 is unsuccessful as indicated by the test 72, y^* incremented by one (operation 80) and a test 81 is carried out to determine whether y^* is less than all other values of y except y_h and if so P_h is replaced by P^* (operation 82). If the test 81 is negative a test 83 is carried out to determine whether y_h is greater than or equal to y^* indicating that P_h is worse than P^* and if so P_h is replaced by P^* (operation 84).

A contract operation 85 (as defined above) follows determining a new point P^{**} and if a test 86 indicates that it provides a better match a function value y^{**} is decremented (operation 87) and P_h is replaced by P^{**} (operation 88). Otherwise y^{**} is incremented (operation 89) and then each point is the simplex is moved halfway towards the best point P_1 in an operation 90 using the equation:

$$P_i = (P_i + P_e)/_2$$

for

$$i = 1 \text{ to } n+1$$

Following each of the operations 77, 79, 82, 88 and 90, a test 92 is carried out asking the sufferer whether a good match has been obtained. If not the simplex is repeated starting at the operation 70 but otherwise the simplex is complete. If a second order simplex is used, that is n=2 the best point found corresponds to the two required coefficients for the lattice filter but if it is required to estimate more parameters a higher order simplex may be used.

Using two coefficients found with the simplex, a tinnitus masker is constructed for the particular sufferer using an apparatus which is similar to Figure 3 in that it uses a microcomputer and an EPROM but a digital speech synthesiser is used, in a somewhat different way, instead of the sound generator 52. The EPROM in addition to storing the coefficients found using the simplex algorithm also stores the data coded using the linear prediction algorithm for the particular sound required by the sufferer who is to use the masker. As with the arrangement of Figure 3 several different masks can be stored and selected by operation of an external switch.

A simple masker which can be set up by hand is now described with reference to Figure 6. Having characterised the tinnitus in one of the ways described an audiologist with some experience of the types of equipment mentioned above can manually program the masker of Figure 6 using five potentiometers VR1 to VR5 and seven switches SW1 to SW7.

A programmable sound generator 100 (type SN 76477) forms the basis of the masker and comprises a super low frequency oscillator, a voltage controlled oscillator (VCO), a noise generator and an envelope generator and modulator. These circuits are shown in the manufacturer's data but not in Figure 6. The super low frequency oscillator supplies signals to the mixer and the VCO and its frequency is determined by the potentiometer VR2, a resistor R9 and a capacitor C2 connected as shown to pins 20 and 21 of the generator 100. (The numerals shown inside the integrated circuits of Figure 6 relate to pin numbers).

The VCO produces a tone whose frequency is dependent on the setting of the potentiometer VR1 connected to pin 16. The method of controlling the VCO is selected by switch SW5 connected to pin 22 so that when a low logic level is applied by closing the switch SW5 the VCO is controlled by the potentiometer VR1. When the switch SW5 is open a high logic level is applied to pin 22 and the VCO frequency is controlled by a triangular waveform signal generated by the super low frequency oscillator. A resistor R10 and a capacitor C3 connected to points 18 and 17 respectively control the minimum frequency of the VCO. By connecting pin 19 to a regulated five volt supply available from pin 15 a 50% duty cycle is achieved at the VCO output. The noise generator is operated by a noise clock signal which is generated by one half of a dual timer 101 (type NE 556). Noise frequency is controlled by the potentiometer VR3, resistors R17 and R19 and a capacitor C6.

The noise generator produces psuedo random white noise which is passed through a variable bandwidth low pass filter before being applied to the mixer. The 3-dB roll-off point of the filter is controlled by the potentiometer VR4 in conjunction with a resistor R12 and a capacitor C4.

The mixer selects one or more of the outputs of the VCO, the super low frequency oscillator, and noise according to logic signals applied at pins 25, 26 and 27 of the generator. It will be seen that switches SW3, SW4 and SW6 in conjunction with resistors R4, R5 and R6 allow either a high or low logic level to be applied to these pins. The combination of logic signals for various outputs is as given in the manufacturer's data for the SN 76477 sound generator.

Multiplexing the VCO, the super low frequency oscillator and the noise generator is achieved by applying a logic signal to the pin 25 which varies between high and low. To this end when more than one noise source is required a switch SW1 is closed. The frequency at which multiplexing is carried out is controlled by resistors R1 and R2 and a capacitor C1 and the other half of the dual timer 101, pins 1, 2 and 6 of the timer being the discharge, threshold and trigger pins, respectively. The square wave output for multiplexing is generated at pin 5 of the timer.

Various envelope functions are available by applying high and low logic signals to pins 1 and 28 of the sound generator by means of resistors R3 and R8 and switches SW2 and SW7. The

options available are VCO, mixer only, one-shot and VCO with alternating cycles and the manufacturer's data explains which logic signals are required for each alternative. A resistor R3 is connected to pin 10 to set the attack (rate of rise) of any envelope selected.

If it is required to synchronise the sound generated with a sufferer's heartbeat a monitor, such as that mentioned in connection with Figure 1, is connected to terminal 9. With the single shot envelope selected by closing the switch SW7 and opening the switch SW2 each high to low transition on the terminal 9 triggers a single shot. The terminal 9 is connected to earth if synchronisation is not required.

An audio amplifier comprising transistors TR1 and TR2 is connected at output pin 13 and provides an output signal at terminals 102 for headphones. A resistor R15 connected at pin 12 is a feedback resistor and volume control is provided by the potentiometer VR5 and a resistor R16.

A nine volt power supply is applied to the audio amplifier and to the V_{cc} pin 14 and since the SN 76477 generator includes an internal voltage regulator and regulated five volt output then appears at pin 15. Pins 7, 8, 9, 24 and 25 of the generator 100 and pins 3 and 11 of the timer are not connected.

Examples of some possible modes of operation are now given:—

With switches SW2, SW4, SW5 and SW6 closed white noise is obtained and by opening switch SW4 a tone is combined with the white noise. Closing switches SW2, SW3, SW4 and SW5 provides a pulsing noise and opening switch SW4 then gives white noise and a tone with a pulsatile envelope. Closing switches SW2 to SW6 provides a tone and then if the switch SW5 is opened the tone is swept through a range of frequencies.

The masker shown in Figure 6 is set up by selecting the appropriate mode (using the switches SW1 to SW7) as defined by the characterisation and then the tone frequency, noise bandwidth and pulse rate are set using potentiometers VR1, VR4 and VR3, respectively.

Typical component values for Figure 6 are as follows:—

R1, R10—47 KΩ
R2, R9, R13, R16—100 KΩ
R3, to R8—10 KΩ
R12—7.5 KΩ
R14—6.8 KΩ
R15—2.2 KΩ
R17, R19—4.7 KΩ
C1—220 pF
C2—1 μF
C3—0.01 μF
C4—1 nF
C5—10 μF
C6—220 pF
VR1, VR3—100 KΩ
VR2, VR4, VR5—1 MΩ

A second simple masker shown in Figure 7 is now described. A broad band noise source 100 is coupled to an input terminal of a switched capacitor filter 101 which in this example is an integrated circuit type MF10 where the input terminal is pin 4. The noise source may include a diode, or junction of a transistor, reverse biased to breakdown and an amplifier for the resultant noise signal. The output terminal (pin 2) of the filter 101 is coupled to an audio amplifier 102 which has a gain control (not shown) for the sufferer. The sufferer's earpiece 103 (or headphone) is coupled to the output of the amplifier. The bandwidth of the filter 101 is controlled by a variable resistor 104, connected between pins 2 and 4. The centre frequency of the filter pass band is controlled by a variable-frequency clock circuit 107 coupled to pin 10 of the filter 101 by way of an AND gate 108. A further variable-frequency clock circuit 110 is coupled to enable the gate 108 at a frequency dependent on any pulsatile tinnitus a sufferer may have, but if the tinnitus is not pulsatile then the gate 108 and the clock circuit 110 may be omitted or the gate 108 can be permanently enabled. If required the gate 108 can be enabled by a heartbeat monitor, such as that mentioned in connection with Figure 1, the clock circuit 110 being omitted.

Having characterised the sufferer's tinnitus the centre frequency and bandwidth of the filter 101 are set up to correspond to the tinnitus, usually as a match, using the frequency control of the clock circuit 107 and the variable resistor 104, respectively. Where required the frequency of the clock 110 is also set up to the sufferer's requirements. The controls for these variables may be calibrated to allow them to be set directly rather than by experiment and measurement.

Two further resistors 105 and 106 are used in conjunction with the variable resistor 104 and two more 115 and 116 are used to provide an appropriate voltage at pins 5 and 15. If the noise source 100 has an output impedance of about 100 KΩ suitable values for the resistors 105, 106, 115 and 116 are each 10 KΩ with the variable resistor 104 having a maximum value of 100 KΩ.

Four superimposed examples of separate narrow band noise spectra which may be obtained with the circuit of Figure 7 are shown in Figure 8, the peaks of bands 111, 112, 113 and 114 occurring at 500 Hz, 1 KHz, 2 KHz and 5 KHz, respectively.

Although specific embodiments of the invention have been described it will be apparent that the invention can be put into operation in many different ways. For example many other circuits than those described can be used to construct maskers according to the invention.

Claims

1. Apparatus for use in connection with tinnitus comprising at least one electrical signal-to-sound transducer suitable for positioning in, or adjacent to, the ear of a tinnitus sufferer, at least

one tone-generating means coupled to the transducer for generating an alternating electrical signal which causes the transducer to generate an audible tone, and means for adjusting the frequency and/or amplitude of the said signal.

2. Apparatus according to Claim 1 including an electrical noise source, and means for adjusting at least one of the following: noise bandwidth, the centre frequency of the noise band and noise amplitude.

3. Apparatus according to Claim 1 or 2 for use in connection with pulsatile tinnitus including control means for controlling the tone generating means and/or the noise source so that pulses of tone and/or noise are generated by the transducer.

4. Apparatus according to Claim 3 including pulse monitor means, adapted to be worn by the sufferer, for generating a synchronising signal once each heartbeat, the pulse monitor being coupled to the control means to synchronise the pulses with the heartbeat.

5. Apparatus according to any preceding claim for characterising tinnitus including means for indicating and/or recording at least some of the following: the frequency of each tone and its amplitude, and the bandwidth, centre frequency and amplitude of the noise.

6. Apparatus according to Claim 5 wherein the tone-generating means comprises an integrated-circuit programmable sound generator, and the means for adjusting frequency and/or amplitude and the means for indicating and/or recording comprise a microprocessor development system, a visual display unit and a keyboard.

7. Apparatus according to Claim 5 insofar as dependent on Claim 2 wherein the noise source and adjustment means comprise an integrated-circuit speech synthesiser, and the means for adjusting frequency and/or amplitude and the means for indicating and/or recording comprise a microprocessor development system, a visual display unit and a keyboard.

8. Apparatus according to Claim 7 wherein the speech synthesiser includes a lattice filter and the microprocessor development system is programmed for interactive response from a tinnitus sufferer to optimise at least some coefficients of the filter.

9. Apparatus according to any of Claims 5 to 7 comprising a control for use by a sufferer for indicating by means of possible first and second actions only whether a sound generated by the apparatus is more or less like the sufferer's tinnitus, or is more or less effective in masking the tinnitus, and means for adjusting the sound generated by the transducer in accordnace with signals from the sufferer's control.

10. Apparatus according to Claim 9 including an adjustable electrical filter and means for implementing a simplex method which evaluates coefficients for the filter each time the sufferer's control is operated, the simplex being arranged to converge gradually to an optimum set of coefficients.

11. Apparatus according to any of Claims 5 to 10 wherein the means for indicating and/or recording includes means for coupling an integrated circuit programmable read-only memory to contain data characterising a tinnitus.

12. Easily personnally portable apparatus for use in a particular tinnitus suffer comprising at least one electrical signal-to-sound transducer suitable for positioning adjacent the ear of the said sufferer, and at least one tone generating means coupled to the transducer for generating an alternating electrical signal which causes the said transducer to generate an audible tone having a frequency and/or amplitude such that the tinnitus of the said sufferer is alleviated.

13. Apparatus according to Claim 12 including means for generating noise having a bandwidth and/or amplitude and/or centre frequency such that the tinnitus of the said sufferer is alleviated.

14. Apparatus according to Claim 12 or 13 including means for generating a pulsatile signal envelope for the tone and/or noise.

15. Apparatus according to Claim 14 including means for synchronising the signal envelope with the suffer's heartbeat.

16. Apparatus according to any of Claims 12 to 15 wherein the tone-generating means comprises an integrating circuit sound generator controlled by an integrated circuit microcomputer wherein data for sounds generated is stored in an integrated-circuit programmeable read-only memory.

17. Apparatus according to any of Claims 12 to 16 including an integrated circuit programmable read-only memory containing data characterising the sufferer's tinnitus, programmed by apparatus according to Claim 5.

18. Apparatus for use in connection with tinnitus comprising at least one electrical signal-to-sound transducer suitable for positioning in, or adjacent to, the ear of a tinnitus sufferer, at least one electrical noise source, and means for selecting both the centre frequency of a noise band for application to the transducer and the bandwidth of the noise band.

19. Apparatus according to Claim 18 wherein the noise source is a broad band source, and the means for selecting the centre frequency of the noise band and its bandwidth is an adjustable filter.

20. Apparatus according to Claim 18 or 19 for use in connection with pulsatile tinnitus including means for controlling the noise source or the selection means so that pulses of noise are generated by the transducer.

21. Apparatus according to Claim 20 including pulse monitor means, adapted to be worn by the sufferer, for generating a synchronising signal once each heartbeat, the pulse monitor being coupled to the control means to synchronise the pulses with the heartbeat.

22. Apparatus for use in connection with tinnitus substantially as hereinbefore described

with reference to any of Figures 1, 3, 4, 6 and 7 of the accompanying drawings.

23. A method for use in connection with alleviating tinnitus substantially as hereinbefore described.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1984. Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.